Chapter 4

METHODS FOR DEVELOPING MINIMUM FLOW CRITERIA

INTRODUCTION

The following chapter describes the methods used for establishing the St. Lucie River and Estuary MFL criteria as required in Chapter 373, Florida Statutes.

The District has investigated resources and issues in the St. Lucie Estuary since 1973. The St. Lucie Estuary plays a pivotal role in the operation of the Central and Southern Florida Project for Flood Control and other purposes. This estuary is the receiving body for discharges from three canals of the primary water control system in South Florida. And provides the eastern connection between the Intracoastal Waterway and the Okeechobee Waterway. In addition, the SLE is one of two receiving bodies for most of the excess water that must be periodically discharged from Lake Okeechobee. The need for the District and United States Army Corps of Engineers (USACE) to study this system has been primarily driven by efforts to document the effects of water releases from major canals; provide better methods for release of excess water from Lake Okeechobee; stabilize the St. Lucie (C-44) canal banks to prevent sloughing and subsequent dumping of sediments to the estuary; and better manage Central and South Florida Project facilities to protect the resources of the St. Lucie Estuary and adjacent waters.

Examples of prior studies by the USACE to determine the effects of discharges from the St. Lucie Canal on the estuary include the following:

Biological studies of resources in the estuary (Philips and Ingle, 1960; Philips, 1961)

Studies of effects of discharges from the canals on these resources (Murdock, 1954; Gunter and Hall, 1963,) and ,

Studies of erosion of the St. Lucie Canal and associated sediment problems in the estuary, (USACE 1976;1994; Williams et al., 1986).

In addition, studies by the District have been conducted for more than 25 years to determine:

Controlled experiments to measure the impacts of high volume releases of water on the estuary. (Haunert and Startzman, 1980; 1985).

An inventory of species and habitats (Woodward-Clyde, 1998; 1999)

Assessment of bathymetry, sediments, water quality and nutrient loading , in the estuary (Morris, 1986; Haunert, 1988; Chamberlain and Hayward, 1996; Dixon et al. 1994; Schropp et al., 1994)

Studies of relationships between hydrologic conditions and productivity (Doering ,1996; Estevez et al., 1991)

- Literature surveys and mathematical modeling to determine historic watershed characteristics, runoff and salinity conditions in the estuary (see papers by VanZee in **Appendix D** and McVoy in **Appendix E**)
- Mathematical modeling to determine effects of present and future freshwater flow regimes on the estuary (Morris, 1987; Hu, 2000; Lin 2001 in **Appendix C**; and Qiu 2001 in **Appendix F**)

Recently, efforts have shifted toward the need to determine minimum flows and levels requirements for this system to protect the estuary from significant harm. To initiate this effort, the District contracted with a consultant to conduct a literature review and examine methods being used elsewhere in Florida, and nationwide, to determine the best strategy for MFL development (Estevez 2000). This review had several objectives as follows:

- To learn of living resources that can be used as targets, indicators, or criteria for minimum flow determinations in riverine estuaries
- To learn how the selection of living resource targets may be affected if working in rivers with long histories of extreme structural and hydrologic alteration
- To benefit from lessons learned by other Florida water management districts, other states, and other countries
- To solicit an independent expert recommendation of approaches to develop flow management criteria, so as to improve water quality, increase habitat for key organisms, and sustain biodiversity

This effort resulted in specific analyses and recommendations concerning the development of MFLs for the St. Lucie Estuary, including a summary of the relevant goals and objectives, assessment of current knowledge concerning this system, assessment of resources that could provide a basis for establishing quantitative relationships between flows and impacts, and recommended technical approaches. This information was assessed by District staff then combined with new information, based on the approaches suggested in this review, to develop technical relationships for minimum flows and levels.

Management Goals (Estevez, 2000)

Several accounts made by or for the South Florida Water Management District portray ecological changes to the system during the previous century. Chief among these were sedimentation, sediment contamination, altered seasonal flows, highly varying salinities, loss of submerged aquatic vegetation, changes in distribution and composition of oyster reefs, hypoxia and anoxia, phytoplankton blooms, low transparency, and declines in abundances of valued fish species.

Taken as a whole, these changes may be understood as the consequence of two opposing trends affecting the St. Lucie Estuary. On the one hand, the St. Lucie Estuary is becoming more saline because an inlet was opened, channels were dug, sea level continues to rise, and local aquifers are salinized or depleted. On the other hand, this system is becoming more freshwater in nature because flood control canals were constructed, the estuary was connected to Lake Okeechobee, and runoff from impervious urban developments is increasing.

The District seeks to improve the management of freshwater inflow to the estuary. The minimum flow program will be used to define inflow regimes that cause significant harm. Efforts such as the Comprehensive Everglades Restoration Plan (CERP) and the associated Indian River Lagoon Feasibility Study provide means to restore some of the system's lost hydrologic and ecological functions. To guide these efforts, the District has employed three sets of provisional or working goals for the estuary:

Set 1. "Make the benthic environment continuously inhabitable by epifauna and infauna, in densities and diversities that exceed those typical of pollution-indicator communities," and also "make bottom and water conditions able to support some amount of submerged aquatic vegetation, where it presently does not occur in the estuary (Estevez et al. 1991c) ."

Set 2. "Improve and maintain the health of the St. Lucie estuary ecosystem (by) promoting and sustaining a healthy oyster population; freshwater, brackish, and marine submersed vegetation; juvenile marine fish and shellfish, and successful recreational and commercial fisheries (Dixon et al. 1994) ."

Set 3. "Protect, enhance, and rehabilitate estuarine ecosystems" (SFWMD, 1998) by "improving water quality, increasing available habitat for key organisms, and sustaining biodiversity (SFWMD, 1999)."

Management Objectives

Based on this analysis, consideration of the impacts of hydrologic alterations that have occurred to the system and assessment of existing resources (see below), hydrologic management objectives for the St. Lucie Estuary to achieve these goals should address the following concerns:

Reduce high level discharges that have severely impacted the central estuary and adjacent coastal waters by causing rapid and extreme fluctuations in salinity and deposition of large amounts of sand and organic sediments.

Improve water quality by limiting the amount of nutrients and pollutants that enter the estuary.

Protect and enhance hydrologic conditions in the remaining natural river systems and watersheds, especially the remaining North Fork River and South Fork River systems.

Ensure maintenance of a persistent, but not necessarily extensive, oligohaline zone habitat.

Development of MFL criteria provides one of many tools that are needed to address these goals and objectives. These criteria will specifically help maintain oligohaline areas, which will, in turn, help protect and enhance natural systems.

ESTABLISHING HYDROLOGIC MANAGEMENT CRITERIA

Conceptual Basis for Minimum Flows

River management is a complex process that requires consideration of a number of variables. Minimum flows are an important component of riverine flow characteristics. However, providing a minimum flow represents only one aspect of management and/or restoration of river hydrology. Focus on a single aspect of river hydrology (minimum flows) is an overly simplistic treatment of complex ecosystem interactions. In spite of recent advances in our understanding of river hydrology, long-term hydrological data, especially measures of variability have been under-utilized in most management decisions aimed at river ecosystem protection or restoration (National Research Council, 1992).

Estuarine scientists and managers have also objected to the idea that minimum flows can be set for estuaries, because of their intrinsic ecological complexity. Complexity in itself is not a sufficient reason to question the concept of minimum flows for estuaries; In fact, it simply supports the fact that complex biological systems, such as those in estuaries, require more study. Due to the lack of understanding and a shortage of previous attempts to establish minimum flows, estuarine scientists and managers do not have even simplistic minimum flow examples to study or criticize. Rather than waiting until all information is available before making a management decision, the best approach may be to set inflows based on some simplistic assumptions and monitor the results for success or failure

Recent Advances in Flow Analysis

Restoring Natural Flow Regimes.

Because modifications of hydrologic regimes in rivers are known to directly and indirectly alter the composition, structure, or function of riverine aquatic and wetland ecosystems, most river scientists tend to agree that it is better to approximate natural flow regimes and maintain entire ensembles of species, than to optimize water regimes for one or a few species. In reality, however, the great majority of instream determinations have been based on one or a few species' requirements. It is now understood that native aquatic biodiversity depends on maintaining or creating some approximation of natural flow variability, and that native species and communities will perish if the environment is pushed outside the range of natural variability. Where rivers are concerned, a natural flow paradigm is gaining acceptance. It states "the full range of natural intra- and inter-annual variation of hydrologic regimes, and associated characteristics of timing, duration, frequency and rate of change, are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems" (Richter et al., 1997). A corollary idea is that ensembles of species and ensembles of habitats should be used to gage the effect of hydrological alteration.

There is growing sentiment for a similar paradigm in estuaries. In riverine estuaries it seems reasonable to evaluate both flows and salinities with respect to their multiple forms of variation, in the latter case leading to the idea that "the full range of natural intra- and interannual variation of salinity regimes, and associated characteristics of timing, duration, frequency and rate of change, are critical in sustaining the full native biodiversity and integrity of estuarine ecosystems."

Richter "Range of Variability" Criteria

A new and robust method was developed for determining hydrologic alterations in rivers (Richter et al., 1996). The "Range of Variability Approach" is based on the calculation of means and coefficients of variability, of 32 hydrologic variables grouped into five sets:

Magnitude of monthly water condition

Magnitude and duration of annual extreme conditions

Timing of annual extreme water conditions

Frequency and duration of high and low pulses

Rate and frequency of water condition changes

Comparisons are made between "before" and "after" modifications. In the absence of "before" data, models can be used to estimate water conditions. Some alterations affect only a few indicators, whereas others affect many. Patterns of alteration help managers determine which aspects of flow to modify.

This technique employs more variables and offers more promise in protecting ecosystem integrity. It is gaining in popularity and has been used extensively by the Northwest Florida Water Management District in its role in the ACF Tri-State Compact (USACE, 1998). In cases where restoration is sought for a system with no "natural" flow data it is necessary to employ hydrologic simulation models to estimate historic conditions. While such models may provide good estimates of impact magnitude they do not illuminate their causes, Nevertheless, the method captures a number of features, especially rates of change, that are not being used in estuarine science and management.

The "Range of Variability Approach" can be applied, even when flow data are scant, to set initial river management targets for rivers in which the flow regime has been greatly altered by human developments such as dams and large diversions. If adequate stream flow records exist for at least 20 years of natural conditions, the method can be used directly. In the absence of all 20 years of data, missing data can be estimated. In the absence of any data, models may be employed or normalized estimates can be generated from nearby, similar streams. Some hydrologic variables cannot be generated by these latter methods, affecting the power of the technique.

The criteria for streams pose great difficulty for estuarine managers where tributary data are sparse; where tributaries have been extensively altered for long periods of time; or where regulated flows are only part of an estuary's total freshwater budget.

SYNTHESIS AND APPLICATION

Methods Considered for Use in the St. Lucie Estuary

Several general methods were identified that could be used to establish minimum flows for the St. Lucie River and Estuary. Components of five possible approaches are integrated in this study. These methods are described in general terms below, followed by assessments of their applicability.

1. Instream Flow Methods. Historic flow, hydraulic, or habitat methods can be used to determine acceptable flows of individual tributaries to rivers. This approach presumes that an estuary's needs for freshwater can be met by providing sufficient water to the streams that flow into it. The approach requires that the majority of estuarine inflow be via streams or other gaged surface waters and that data are available or can be obtained.

2. Hydrological Variability Techniques. Following Richter et al. (1996) this approach extends the instream techniques through a fuller analysis of flow characteristics. An untested but feasible application of the method would be its use with salinity data rather than flow data. Data requirements are large but most types of salinity data could be generated through the use of models. Results of natural or historic conditions would be compared to existing or predicted conditions of salinity.

3. Habitat Approaches. Browder and Moore (1981) proposed the concept of analyzing the overlap of dynamic and stationary habitat elements for particular species. This ap could be developed more fully. If submerged aquatic vegetation was targeted, for example, the method would query the probability that appropriate depths, sediment types, salinities, and conditions of water clarity coincided under differing flow regimes.

4. Indicator Species. This approach relates a change in abundance, distribution, or condition of particular species to a flow or salinity. Criteria for selection may include a species' commercial, recreational, or aesthetic value; ecological importance; status as a species at risk (threatened, endangered, etc.), or endemism. Statistical methods attempt to match abundance values to appropriately time-lagged inflow or salinity conditions.

5. Valued Ecosystems Component (VEC) Approaches. An extension of the indicator species approach, VEC analysis also uses statistical methods but accounts for more known or suspected intermediate variables. Recommended by the USEPA (1987) for National Estuary Programs to characterize constraints to living resources, VEC analysis plays an important part in a general model for the design of eutrophication monitoring programs in South Florida estuaries. VEC is a goal-driven approach that has the ability to focus research and provide managers with short-term alternatives in data-poor estuaries.

Assessment of These Methods Relative to the St. Lucie Estuary

Instream flow methods have limited applicability in the St. Lucie Estuary because of physical changes wrought to natural tributaries and the overwhelming influence of canals. Prospects of using hydrological variability techniques also are poor, for the same reason. In order for this method to work, it would be necessary to employ a natural systems model of the St. Lucie watershed and compare the five Richter classes of hydrologic variability to present-day conditions. Such hindcast models may not be reliable sources of data for every Richter comparison. Attempts to compare salinities computed from a natural systems model suffer even larger challenges. Although this modeling approach may not provide all of the information needed to manage water flows to the estuary, District staff felt that it could be used successfully to examine one aspect of flow, namely the MFL criteria.

Habitat approaches offer some promise in the St. Lucie Estuary. The District already is working with shoal grass (*Halodule wrightii*) and American oyster (*Crassostrea virginica)* in this regard. Based on a literature review for other St. Lucie Estuary species (Woodward-Clyde 1998), widgeon grass (*Ruppia maritima*) and tape grass (*Vallisneria americana*) merit consideration as part of an oligohaline submerged aquatic vegetation community. Although both of these species occur in the St. Lucie system, they are not widespread or persistent, probably due to rapid changes in salinity. District staff determined that although such approaches may be feasible in the future, not enough information is currently available concerning distribution, life histories and salinity tolerance to establish quantitative relationships between low rates of freshwater flow and impacts on populations of these organisms in the St. Lucie Estuary.

Since a dominant issue within the St. Lucie Estuary is the prolonged duration and spatial expansion of oligohaline waters, a general "oligohaline habitat" merits formal spatial analysis. In light of District goals (Set 2 on page 4-3), the St. Lucie Estuary should possess a permanent low-salinity reach, but not an extensive, persistent one. The difficulty of working with habitats that presently are rare or absent is acknowledged. In the St. Lucie Estuary, for example, it may be necessary to plant submerged aquatic vegetation or cultch for oysters to overcome historic recruitment bottlenecks, and then study their responses to managed flows and salinities. Flows could be varied experimentally, or adopted flows could be monitored through time so as to allow periodic assessments of progress and adjustments to flow.

Indicator species can be suggested in addition to submerged aquatic vegetation and oysters, using as guidance the size and value of existing literature for each and their previous successful use in other estuarine inflow studies. Sedentary species such as *Mercenaria*, *Corbicula* or *Rangia* clams, migratory organisms such as Blue crabs *(Callinectes sapidus*) and planktonic fish eggs and larvae have been suggested. The advantages of each include their relative ease of capture and estimation of abundance by fishery-independent methods, and the ability to analyze results against salinity and inflow by calculating their respective salinities of maximum abundance (Peebles et al. 1991). The main disadvantage of their use is the time required to collect adequate time-series of data, because statistical methods attempt to match abundance values to appropriately time-lagged inflow or salinity conditions. Insufficient data are presently available to support the use of indicator species as a basis to establish MFL criteria.

Species identified under habitat approaches or indicator species may be taken as valued ecosystem components. By the VEC method, empirical goals would be stated for the status of each. Causal links would be identified from the status of each species back through proximate and ultimate controlling factors. In a series of reports for the District, Mote Marine Laboratory developed and applied in the St. Lucie estuary a model methodology incorporating VEC analysis (see Set 1 goals, page 4-2).

Proposed VEC for the St. Lucie Estuary.

The SFWMD Coastal Ecosystem Department's research program supports application of a resource-based management strategy defined as the "Valued Ecosystem Component" (VEC) approach. This evaluation methodology is similar to a program developed as part of the National Estuary Program (United States Environmental Protection Agency 1987). For the purposes of this study, the VEC approach is based on the concept that management goals for the St. Lucie River and estuary can best be achieved by providing suitable environmental conditions that will support certain key species, or key groups of species, that inhabit this system.

A VEC can be defined as a species, community or set of environmental conditions and associated biological communities that is considered to be critical for maintaining the integrity of this estuarine ecosystem. District staff propose that the oligohaline zone in the St. Lucie Estuary is a VEC for purposes of establishing minimum flow conditions for the North Fork of the St. Lucie River. Loss or reduction of this resource below a critical level is considered to constitute significant harm.

PROCESS USED TO DEVELOP MFL CRITERIA

Literature Review

Importance of the Oligohaline Zone

A report (Robbins, 2001) summarizing available literature regarding species that occur in the oligohaline zones in estuaries was developed to assist with development of minimum flows and levels criteria for the St. Lucie Estuary. This report is included in **Appendix B** and summarized below. Based on results of this study, District staff infer that the oligohaline zone in the St. Lucie estuary must be important because it provides important habitat for many species that utilize the river, the adjacent Indian River Lagoon and the offshore reefs.

An estuary is defined as the area where a river meets the ocean. Freshwater from the river carries nutrients and organisms into the estuary where they provide a nutritional basis for a highly productive transitional food chain. The resulting change in salinity conditions produces a stressful environment that on the one hand restricts the number of organisms, but on the other hand provides a highly productive environment for those species that are adapted to survive this stress.

The oligohaline zone in an estuary is an area where salinity conditions are low. Although the exact definition may vary among authors, it is generally considered to occur within the range from 0.5 to 5.0 ppt salinity. This zone is important because it supports important physical, chemical and biological processes that are necessary to maintain the range of ecological, species and habitat diversity in the region that includes the St. Lucie River system, the Indian River Lagoon and adjacent waters of the Atlantic Ocean. The oligohaline zone provides a buffer or interface between fresh and marine waters that provides habitat and a nursery function for juveniles and adults of both estuarine and marine organisms. These organisms include the juveniles and adults of fishes, shrimps and crabs that support important regional food fisheries and sport fishing. A broader array of other species that provide necessary food sources and habitat, including aquatic vegetation, microinvertebrates, macroinvertebrates and insects also inhabit this zone. A list of representative species that occur in oligohaline waters in the St. Lucie Estuary is provided in **Table 4-1.**

Table 4-1. A Partial List of Fish and Shellfish Collected in Oligohaline Waters.

Scientific Name	Common Name	Size Class			Reference (see **Appendix B** for full citations)
		Adult	Juvenile	Not Specified	
Achirus lineatus*	Lined sole			✔	Hackney and de la Cruz 1981
Albula vulpes*	Bonefish		✔		Haunert and Startzman 1985
Anchoa mitchilli*	Bay Anchovy	✔	✔		Gunter 1961; Gunter and Hall 1963; Markle 1976; Day et al. 1980, Hackney and de la Cruz 1981; Rozas and Hackney 1984; Felley 1987; Hastings et al. 1987; Peterson and Ross 1991; Edwards 1992
Archosargus probatocephalus*	Sheepshead			✔	Hastings et al. 1987
Arius felis*	Hardhead catfish	✔	✔	✔	Hastings et al. 1987; Edwards 1992; Gunter and Hall 1963
Astroscopus sp.	Stargazer			✔	Rozas and Hackney 1984
Bagre marinus*	Gafftopsail catfish			✔	Hastings et al. 1987
Bairdiella chrysoura*	Silver perch			✔	Markle 1976; Rozas and Hackney 1984
Brevoortia smithii*	Fine-scale menhaden		✔		Gunter and Hall 1963
Brevoortia tyrannus*	Atlantic menhaden		✔		Rozas and Hackney 1984
Callenectes sapidus*	Blue crab	✔	✔		Gunter 1961; Day et al., 1980; Hackney and de la Cruz 1981
Caranx hippos*	Crevalle jack			✔	Hastings et al. 1987
Centropomus undecimalis*	Snook		✔		Gunter and Hall 1963; Haunert and Startzman 1980, 1985; Peterson and Gilmore 1991; Edwards 1992
Citharichthys spilopterus*	Bay whiff			✔	Hastings et al. 1987
Crangon septemspinosa	Sand shrimp			✔	Hughes et al. 2000
Cynoscion arenarius	Sand seatrout			✔	Hastings et al. 1987
Cynoscion nebulosus*	Spotted seatrout		✔	✔	Hackney and de la Cruz 1981; Edwards 1992
Cynoscion regalis*	Weakfish			✔	Markle 1976
Cyprinodon variegatus*	Sheepshead minnow			✔	Hastings et al. 1987
Dasyatis sabina*	Atlantic stingray			✔	Hastings et al. 1987
Diapterus olisthostomus*	Sand perch			✔	Gunter and Hall 1963
Diapterus plumieri*	Striped moharra			✔	Edwards 1992
Dorosoma cepedianum*	Gizzard shad			✔	Rozas and Hackney 1984; Haunert and Startzman 1985; Hastings et al. 1987
Dorosoma petenense*	Threadfin shad			✔	Hastings et al. 1987
Elops saurus*	Ladyfish		✔	✔	Govoni and Merriner 1978; Haunert and Startzman 1985; Hastings et al. 1987
Enneacanthus gloriosus*	Bluespotted sunfish			✔	Rozas and Hackney 1983 citing Raney and Massmann 1953
Euciniostomus juveniles*	Moharra		✔		Edwards 1992
Eucinostomus argenteus*	Spotfin Mojarra			✔	Gunter and Hall 1963

Evorthodus lyricus*	Lyre goby			✔	Hackney and de la Cruz 1981; Rozas and Hackney 1984
Fundulus confluentus*	Marsh killifish			✔	Hackney and de la Cruz 1981
Fundulus grandis*	Gulf killifish			✔	Hackney and de la Cruz 1981; Hastings et al. 1987
Fundulus seminolis*	Seminole killifish			✔	Edwards 1992
Gambusia affinis*	Mosquito fish	✔	✔		Gunter and Hall 1963; Rozas and Hackney 1984; Haunert and Startzman 1985; Hastings et al. 1987; Edwards 1992
Gobionellus boleosoma*	Darter goby			✔	Gunter and Hall 1963
Gobionellus hastatus*	Sharptail goby			✔	Rozas and Hackney 1984
Gombiosoma bosci*	Naked goby			✔	Hackney and de la Cruz 1981; Hastings et al. 1987
Heterandria formosa*	Least killifish			✔	Gunter and Hall 1963; Hastings et al. 1987
Ictalurus catus*	White catfish	✔	✔		Gunter and Hall 1963; Markle 1976; Rozas and Hackney 1984; Haunert and Startzman 1985
Ictalurus nebulosus*	Brown bullhead			✔	Gunter and Hall 1963
Ictalurus punctatus*	Channel catfish			✔	Markle 1976; Hastings et al. 1987
Lagondon rhomboides*	Pinfish			✔	Rozas and Hackney 1984; Edwards 1992
Leiostomus xanthurus*	Spot			✔	Markle 1976; Rozas and Hackney 1984; Hastings et al. 1987; Edwards 1992
Lepomis macrochirus*	Bluegill	✔	✔		Hackney and de la Cruz 1981; Hastings et al. 1987; Edwards 1992; Deegan and Garritt 1997
Lepomis microlophus*	Redear sunfish			✔	Hastings et al. 1987
Lucania parva*	Rainwater killifish			✔	Hackney and de la Cruz 1981; Hastings et al. 1987; Edwards 1992
Lutjanus griseus*	Gray snapper			✔	Gunter and Hall 1963
Megalops atlanticus*	Tarpon		✔		Haunert and Startzman 1985
Membras martinica*	Rough silverside			✔	Hackney and de la Cruz 1981
Menidia beryllina*	Inland or tidewater silverside			✔	Rozas and Hackney 1984; Felley 1987; Hastings et al. 1987; Peterson and Ross 1991; Edwards 1992
Menidia menidia*	Atlantic silverside			✔	Deegan and Garritt 1997; Hughes et al. 2000
Microgobius gulosus*	Clown goby			✔	Hastings et al. 1987
Micropogon undulatus*	Atlantic croaker		✔	✔	Gunter 1961; Markle 1976; Day et al. 1980; Rozas and Hackney 1984; Hastings et al. 1987
Micropterus salmoides*	Largemouth bass	✔	✔		Hackney and de la Cruz 1981; Hackney and Rozas 1984; Hastings et al. 1987
Mugil cephalus*	Striped mullet*		✔	✔	Haunert and Starzman 1980; Hackney and de la Cruz 1981; Rozas and Hackney 1984; Hastings et al. 1987; Edwards 1992
Mugil curema*	Silver mullet*		✔		Gunter and Hall 1963
Notemigonus crysoleucas*	Golden shiner			✔	Hastings et al. 1987
Oligoplites saurus*	Leatherjacket			✔	Hackney and de la Cruz 1981
Penaeus aztecus*	Brown shrimp		✔	✔	Gunter 1961; Peterson and Ross 1991
Poecilia latipinna*	Sailfin molley			✔	Edwards 1992
Pogonias cromis*	Black drum			✔	Hastings et al. 1987
Pomatomus saltatrix*	Bluefish			✔	Rozas and Hackney 1984; Deegan and Garritt 1997
Pomoxis nigromacuatus*	Black crappie			✔	Rozas and Hackney 1984; Haunert and Startzman 1985; Hastings et al. 1987
Sciaenops ocellatus*	Red drum		✔	✔	Haunert and Startzman 1980; Edwards 1992
Strongylura marina*	Atlantic needlefish			✔	Rozas and Hackney 1984; Hastings et al. 1987
Sygnathus scovelli*	Gulf pipefish			✔	Hastings et al. 1987
Symphurus plagiosa	Blackcheek tonguefish			✔	Rozas and Hackney 1983 citing Rounsefell 1964
Syngnathus louisianae*	Chain pipefish			✔	Rozas and Hackney 1983 citing Dahlberg 1972
Synodus foetens*	Inshore lizardfish			✔	Rozas and Hackney 1983 citing Dahlberg 1972
Trinectes maculatus*	Hogchoker			✔	Gunter 1961; Markle 1976; Hastings et al. 1987; Edwards 1992

* Species found in the St. Lucie Estuary (included in species lists in Gunter and Hall 1963 and/or Haunert and Startzman 1980, 1985).

Extent of Oligohaline Habitat

In his analysis of previous research studies that could provide a basis to establish flow criteria for the St. Lucie Estuary, Estevez (2000) concluded that, the St. Lucie Estuary should possess a permanent, low-salinity reach. Although most of the estuary may become oligohaline during high discharge periods the areas where oligohaline habitat occurred under natural (predrainage) conditions, were the upstream reaches of the major tributary streams and rivers. Many of the natural streams, such as Bessey Creek, have been channelized and their watersheds altered by dredging and filling. However, two relatively extensive riverine systems remain within the watershed -- the North Fork and South Fork rivers.

Hydrologic and Hydrodynamic Methods

To determine a basis for defining MFL criteria for the St. Lucie Estuary, based on significant harm, District staff first defined the nature, importance and extent of the oligohaline zone. Historic and current flow conditions throughout the St. Lucie Estuary were analyzed to determine how flows vary over time. Simulated historic flows were compared with current flows generated using simulated 1995 conditions (see below). Periods of zero or low flow were identified as times when the oligohaline zone was likely to be greatly restricted in extent or eliminated. More detailed investigations were then focused on flow conditions in the North Fork River. Data from the SFWMD's geographic information system (GIS) were used to determine the area and volume of this river system. An existing estuary model was modified to extend the range of the model upstream to the water control structure and to estimate salinity conditions that would occur in this section of the river in response to various flow regimes.

Results of these analyses indicated that the river channel remains relatively narrow for the first three miles below the Gordy Road structure until the confluence of Five Mile Creek. Beyond this location, area increases more rapidly, but still remains a narrow channel until approximately eight miles downstream. At this point the river and floodplain widen into an area of oxbows, islands and channels that result in a rapid increase in river area and volume. This location, eight miles downstream from the Gordy Road structure, is considered a "breakpoint" in the area/volume relationship that has significant effects on the availability of oligohaline habitat.

Results of flow analyses for the North Fork, for historic and 1995 Base Case conditions, indicated that less water flowed to the North Fork under the 1995 Base Case than occurred under the NSM simulation. Further analysis indicated, however, that this reduction in flow occurred primarily during high flow periods and that, in fact, more water was being discharged from the North Fork River to the estuary during low flow periods under the 1995 Base Case simulation than was discharged during similar periods under NSM simulation. Further analyses were therefore conducted to characterize discharges to the estuary during very dry periods.

Assessment of Current and Historic Conditions

In order to assess the past and present extent and nature of oligohaline conditions in the St. Lucie Estuary, assessments were made of present and past conditions in the system with respect to natural systems, land use and hydrology. Present day conditions in the St. Lucie watershed were determined for use in the LEC Regional water supply Plan (SFWMD 2000b). These analyses included assessment of current hydrologic conditions and operation of major canals and structures, recent land use throughout the watershed and estimates of agricultural, urban and industrial water use. This information for the year 1995 was compiled to produce the 1995 Base Case conditions that were analyzed in the LEC Plan.

Basic information from the regional models was used to provide boundary conditions for more specific models that were developed for the St. Lucie Estuary. The 1995 Base Case data were obtained from a 31-year (1965-1995) simulation of the hydrology in today's St. Lucie River Watershed. Five separate basin-scale models were created using the Hydrologic Systems Program Fortran (HSPF) model (see report by Lin [2000] in **Appendix C**).

Historical hydrologic conditions (prior to construction of canals) were predicted using a version of the Natural Systems Model (NSM) that was specifically adapted to the St. Lucie Estuary (VanZee 2000). NSM data are from a 31-year (1965-1995) simulation of the hydrology in the undeveloped St. Lucie River watershed. A report describing this model is provided in **Appendix D**.

Historical land use/land cover conditions in the watershed were determined based on review of historical accounts, maps, surveys, and other data collected from this region (McVoy, 2000--**Appendix E**). Conclusions from this study are based on examination of field notes and plat maps for five of approximately 30 townships that comprise the watershed. Plat maps for a number of additional townships were examined briefly.

Three main physiographic regions appear to have been present in the pre-drainage watershed: 1) an area of pinelands and seasonal ponds mosaic, 2) an area of prairie and seasonal ponds mosaic, and 3) an area referred to as the "Halpatta Swamp," which was later named the "Allapattah Flats."

All three physiographic regions appear to have been very flat, with the elevation difference between pinelands and ponds probably often as little as two feet.

The prairie mosaic was described primarily in the northern portion of the St. Lucie watershed. The sawgrass marshes and bordering forested wetlands that formed the Halpatta Swamp were present along the western edge of the watershed, along the eastern foot of the high NW-SE trending ridge. Cypress occurring in pond-like patches seems to have been confined to the southernmost townships of the watershed.

Although there appears to have been some interconnection among the ponds in the watershed, generally there does not appear to be a strong suggestion of extensive connection nor of extensive surface runoff.

The watershed may have contributed more water to the St. Lucie River base flow through groundwater discharge than through surface runoff. The long duration of standing water in ponds and even longer duration in the sawgrass marshes indicate that the base flow recession, which occurred during dry periods, was a gradual process.

The presence of extensive surface water throughout the watershed, the limited degree of surface runoff, and the overall similarity in land cover characteristics surrounding the headwaters, suggest that the North and South Forks of the St. Lucie River may have had similar discharges.

Since the amount of historical hydrologic data for this system is very limited, the District developed and adapted several mathematical models to provide tools necessary to estimate both historic and present conditions in the estuary. The models were calibrated and verified using available data and applied to estimate past and present conditions in the watershed and estuary.